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OUR CLIMATE

AND

OUR WHEAT-CROPS.

By J. B. LAWES, LL.D., F.R.S., F.C.S.,

AND

J. H. GILBERT, Ph.D., F.R.S., F.C.S.

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OUR CLIMATE AND OUR WHEAT-CROPS.

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INTRODUCTION.

SINCE the publication of our Paper, "On the Home Produce Imports, and Consumption of Wheat," in this 'Journal' in 1868 (vol. vi. s.s., part 2), more than eleven years have passed away, —years during which the agricultural interests of these islands have experienced a transition from a state of great prosperity to one of great depression,—years during which the worst features of our climate have been exhibited in unusual frequency, and which have terminated with a season, not only by far the worst for the wheat-crop since the commencement of our experiments on the continuous growth of the crop in 1843–4, but probably the very worst that has occurred since observers have furnished us with records of temperature and rainfall, and with other weather statistics.

It has been remarked that, so far as climate is concerned, the British Isles are outside the zone favourable to the growth of wheat, and that its successful cultivation is due to the skill of the farmer in contending against adverse meteorological conditions. It is true that the area under the crop is rapidly diminishing, and that its continued growth appears to gravitate to those districts where the climate, or the soil, or the combination of the two, is the most favourable. But the great decline in area cannot be attributed to any general change for the worse in the characters of the climate. Indeed, Mr. Glaisher has recently called attention to the fact that, dividing the last 108 years into six periods of eighteen years each, there is even a slight progressive increase of mean temperature from the first to the last of those six periods. It is to the greatly increased production of wheat in other countries, at a lower cost than in our own, and to low rates of transport, by which it is brought into our markets in quantity and at a price much reducing the value of the home-produce, that the reduced area under the crop is chiefly to be attributed.

As only about 5 per cent. of the total wheat-crop is derived from the soil itself, the remainder coming, directly or indirectly, from the atmosphere, and as the amount of matter accumulated from either source depends mainly on the quantity, and the relations to one another, of heat and moisture, we cannot be surprised that the character of the seasons exercises such a preponderating influence over the growth of our crops. As yet, however, the connection between meteorological phenomena and the progress of vegetation is not so clearly comprehended as to enable us to estimate with any accuracy the yield of a crop by studying the statistics of the weather during the period of its growth. Experience does, indeed, teach us that we may expect better crops under certain conditions of the weather than under others. But it is only by a careful comparison of the characters of the seasons on the one hand, and of the quantity and quality of the produce on the other, for many years, that we can hope to acquire sufficient knowledge to enable us to assign to the various agencies, the sum of which constitutes the climate of the year, their respective values in the production of the crop. As we have said before (this 'Journal,' vol. ix., part 1, p. 96):—" Thus, it is obvious that different seasons will differ almost infinitely at each succeeding period of their advance, and that, with each variation, the character of development of the plant will also vary, tending to luxuriance, or to maturation, that is, to quantity, or to quality, as the case may be. Hence, only a very detailed consideration of climatic statistics, taken together with careful periodic observations in the field, can afford a really clear perception of the connection between the ever-fluctuating characters of season and the equally fluctuating characters of growth and produce. It is, in fact, the distribution of the various elements making up the season, their mutual adaptations, and their adaptation to the stage of growth of the plant, which throughout influence the tendency to produce quantity or quality. It not unfrequently happens, too, that some passing conditions, not indicated by a summary of the meteorological registry, may affect the crop very strikingly; and thus the cause will be overlooked, unless careful observations be also made, and the stage of progress, and tendencies of growth, of the crop itself at the time, be likewise taken into account."

Still, such records as we do possess, of the conditions as to temperature and moisture of different seasons, are sufficient to account in great measure for the great variation in the quantity and the quality of our crops. The actual amount of rainfall must, however, be carefully considered both in connection with its distribution and with the temperature of the period. For example, it is obvious that a given amount of rain, equally distributed through the spring and summer in each of two seasons, will have a very widely different effect on vegetation in the two cases, if the one season should be at the same time a hot and the other a cold one. Or, if the temperature of the two seasons be the same, but the rainfall very different, either in amount, or distribution, or both, so also will the effect on vegetation be very different. It is generally supposed that the temperature of our summers is not, on the average, sufficiently high for the production of abundant and well-ripened crops of wheat; and that it is in the hottest seasons that the produce is the most abundant. This may be the case so far as a certain class of soils is concerned. But a good deal of wheat is grown upon light land, on which the crop suffers considerably in a season of drought or unusual heat. It would appear that the defect of our climate for the production of wheat is more connected with an excess of moisture than with a deficiency of heat, during the periods of active growth and maturing. It is, in fact, when a cold season, or one of only moderate temperature, is accompanied by an excess of rain, that we find the yield of our wheat-crops is the most defective.

I. SEASONS OF HIGH AND OF LOW PRODUCTIVENESS.

Before entering upon any detailed consideration of the peculiarities of the season and of the experimental wheat-crops at Rothamsted, in 1879, we will endeavour to illustrate, in broad outline, the general characters of season under which some of the best and some of the worst wheat-crops of which we have the record, or the experience, have been grown in this country. For this purpose we will disregard any special characters of the seasons in question at Rothamsted, and draw our illustrations entirely from independent data; namely, the records of the observations of temperature and rainfall made at the Royal Observatory at Greenwich; and we adopt, for the most part, those published by Mr. Glaisher. It is obvious that even such data are more or less local in their application; still, they do indicate the general character of the different seasons, and their distinction from one another.

In Tables I. II. and III., which follow, are given the particulars of the temperature and rainfall of fourteen seasons during the present century, each of which was more or less remarkable so far as the growth of the wheat-crop is concerned. These are 1816, 1832, 1833, 1834, 1835, 1853, 1854, 1857, 1860, 1863, 1864, 1868, 1870, and 1879. The first and the last of them, 1816 and 1879, have the character of yielding the two worst wheat-crops within the period included by those dates, if not indeed within the century. Some of the others were, also, seasons of great deficiency; but others, though, as will presently

TABLE I.—TEMPERATURE of SELECTED SEASONS, of HIGH and of LOW PRODUCE of WHEAT.

MONTHS.	Season 1815–16.	Season 1831–2.	Season 1832–3.	Season 1833–4.	Season 1834–5.	Season 1852–3.	Season 1853–4.	Season 1856–7.	Season 1859–60.	Season 1862–3.	Season 1863–4.	Season 1867–8.	Season 1869–70.	Season 1878–9.	Average 108 Years, 1771–1878.
MONTHLY MEAN TEMPERATURE AT GREENWICH.*															
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
October ..	50·1	55·0	51·2	48·3	50·5	47·9	50·9	51·7	50·9	51·8	51·6	48·7	48·9	51·5	49·6
November ..	38·0	44·3	43·7	43·5	44·1	48·9	42·1	40·7	42·1	39·8	45·7	41·4	43·0	39·7	42·3
December ..	36·6	42·0	42·4	44·6	41·0	47·6	34·0	40·2	36·8	43·6	43·2	37·5	37·9	33·7	39·2
January ..	36·3	37·3	34·5	44·4	38·0	42·4	39·0	36·6	39·7	41·8	36·5	37·2	38·3	31·9	36·6
February ..	34·5	36·9	42·4	40·2	41·2	33·3	39·5	39·2	35·7	42·1	36·0	43·0	36·2	38·2	38·7
March ..	39·4	40·5	37·6	44·0	41·0	38·5	43·8	41·8	41·1	43·9	41·3	44·0	39·6	41·2	41·1
April	43·6	47·2	45·2	45·0	46·4	45·2	48·4	45·7	42·9	49·1	48·2	48·1	48·9	43·2	46·1
May	49·3	51·5	59·4	56·9	52·9	52·0	50·9	54·0	53·8	52·0	53·8	57·3	53·4	48·4	52·5
June	55·1	59·2	59·8	61·1	60·0	58·2	55·7	61·8	54·8	58·1	57·4	62·0	60·9	56·9	58·2
July	57·0	61·2	61·1	64·1	64·4	60·3	60·3	64·5	57·9	60·8	61·8	67·5	65·4	58·1	61·6
August ..	56·3	61·0	57·5	62·3	63·3	60·0	60·9	65·8	57·7	61·9	59·6	63·6	61·1	59·9	60·9
September	54·1	56·6	53·5	58·3	57·1	55·3	58·1	59·7	53·4	53·7	56·9	60·5	55·7	56·3	56·5
Average	45·9	49·4	49·0	51·1	50·0	49·1	48·6	50·1	47·2	49·8	49·3	50·9	49·1	46·6	48·6

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* All from Mr. Glaisher's table, Phil. Trans. Part II. 1850, and from a manuscript table kindly supplied by him for the later years; excepting for 1815–16, for which we have calculated the average for each month from Mr. Glaisher's record of the daily temperatures (Report of the Council of the Brit. Met. Soc. May, 1857), as the values so obtained accord better with other records.

TABLE II.—RAINFALL OF SELECTED SEASONS, OF HIGH AND OF LOW PRODUCE OF WHEAT.

MONTHS.	Season 1815–16.	Season 1831–2.	Season 1832–3.	Season 1833–4.	Season 1834–5.	Season 1852–3.	Season 1853–4.	Season 1856–7.	Season 1859–60.	Season 1862–3.	Season 1863–4.	Season 1867–8.	Season 1869–70.	Season 1878–9.	Average 63 Years, 1815–1877.
MONTHLY RAINFALL AT GREENWICH.*															
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
October ..	2·63	5·50	2·53	1·32	0·44	3·75	4·23	1·91	3·60	4·07	1·82	2·14	1·77	1·66	2·8
November ..	1·51	2·10	1·65	2·31	1·32	6·00	1·95	1·25	2·90	1·00	1·59	0·42	2·38	3·45	2·4
December ..	2·26	2·10	1·10	4·84	1·10	2·20	0·80	1·83	2·17	1·59	1·08	1·97	2·77	1·16	2·1
January ..	2·09	1·21	1·10	3·08	0·66	2·11	1·40	2·60	1·81	2·71	0·88	4·19	1·49	2·59	2·0
February ..	1·62	1·60	3·63	0·44	2·64	1·48	1·21	0·20	1·10	0·50	0·76	1·28	0·54	3·82	1·5
March ..	1·88	1·43	0·99	0·66	2·53	1·50	0·32	0·83	1·86	0·70	2·53	1·07	2·05	0·60	1·6
April	2·13	0·44	1·21	0·55	1·10	3·21	0·59	1·40	1·00	0·45	0·82	2·08	0·28	2·60	1·7
May	2·15	1·54	0·22	0·99	3·08	1·50	3·51	0·33	3·90	1·25	2·00	1·67	0·47	3·36	2·0
June	2·41	3·30	2·09	1·54	2·42	2·75	0·91	2·70	5·80	3·91	0·92	0·47	0·39	4·29	1·9
July	4·30	0·66	1·65	5·28	0·33	5·48	1·75	1·10	2·80	0·88	0·27	1·06	2·01	3·72	2·6
August ..	2·53	3·41	1·76	3·30	1·10	2·75	2·61	2·50	3·68	1·82	1·31	2·61	2·02	5·19	2·4
September	2·05	0·44	1·87	0·88	4·18	2·23	0·98	3·40	3·10	2·95	2·76	1·52	1·63	2·87	2·4
Total ..	27·56	23·73	19·80	25·19	20·90	34·96	20·26	20·05	33·72	21·83	16·74	20·48	17·80	35·31	25·4

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* For 1815–16 we adopt data kindly supplied by Mr. George Dines. For 1831–2, 1832–3, 1833–4, and 1834–5, we take the figures given by Mr. James Simpson, Jun. ('Metropolitan Drainage Reports,' 1857, Appendix III.), which also correspond with those adopted by Mr. Dines and others. For 1852–3, 1853–4, 1856–7, 1859–60, and 1862–3, results kindly provided by Mr. William Ellis; and for 1863–4, 1867–8, and 1869–70, Mr. Glaisher's records ('Proceedings and Quarterly Journals of the Meteorological Society') are adopted. For 1878–9, the Registrar-General's weekly returns are taken.

TABLE III.—RAINFALL of SELECTED SEASONS, of HIGH and of LOW PRODUCE of WHEAT.

MONTHS.	Season 1815–16.	Season 1831–2.	Season 1832–3.	Season 1833–4.	Season 1834–5.	Season 1852–3.	Season 1853–4.	Season 1856–7.	Season 1859–60.	Season 1862–3.	Season 1863–4.	Season 1867–8.	Season 1869–70.	Season 1878–9.	Average 55 Years, 1815–1869.
NUMBER OF DAYS ON WHICH 0·01 INCH OR MORE FELL, AT GREENWICH.*															
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
October ..	14	19	16	13	9	15	27	10	23	16	17	21	11	13	14
November ..	11	15	15	10	10	22	11	10	20	8	11	5	11	15	13
December ..	20	19	16	27	7	19	12	13	20	16	8	12	13	16	12
January ..	16	10	9	26	8	20	15	19	22	16	11	21	15	12	12
February ..	9	7	21	11	16	13	8	3	17	9	12	11	12	21	11
March ..	13	14	12	7	19	14	6	10	22	10	15	16	11	14	12
April	14	7	21	7	10	16	7	18	15	9	4	10	6	16	11
May	15	13	3	7	14	12	16	5	16	10	10	6	5	15	11
June	13	13	14	9	7	17	12	9	24	14	10	5	4	20	11
July	24	5	9	13	6	17	15	9	11	3	3	6	10	19	11
August ..	18	17	7	10	4	10	12	11	23	13	5	12	10	20	11
September ..	14	6	14	9	19	15	9	13	17	14	16	9	8	14	12
Total ..	181	145	157	149	129	190	150	130	230	138	122	134	116	195	141

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* According to Mr. Glaisher's records ('Proceedings and Quarterly Journals of the Meteorological Society'), and for 1878–9, the Registrar-General's weekly returns.

be seen, they were in some points essentially different from one another, were nevertheless characterised by yielding very abundant crops, of very good quality; some of them, it is supposed, the most abundant within the period under review. By the side of the particulars of temperature and rainfall of each of those fourteen seasons there are given the mean temperature of 108 years, the average rainfall of 63 years, and the average number of days of rain of 55 years. It will be observed that each "season" is here reckoned to include the last three months of the year preceding that of the crop, as the characters of the autumn and early winter may materially affect the getting in of the seed and the early progress of the plant.

We will first call attention to the characters of four consecutive seasons of reputed very high productiveness, which occurred before the commencement of the Rothamsted experiments, and of which we have only such knowledge as is on record respecting them. These are 1832, 1833, 1834, and 1835. Among this series 1834 was by far the most abundant; and it is generally referred to as one of the most productive of the century. So abundant were these four wheat-crops, that the average price, even under protection, went down from 54*s.* 5*d.* per quarter over the first harvest-year, to 49*s.* 9*d.* over the second, 41*s.* 5*d.* over the third, and 42*s.* 8*d.* over the fourth. The lowest price reached was 36*s.* per quarter in the last week of 1835 and the first of 1836. And such was the distress suffered by the agricultural interest, as the result of abundant wheat-crops, and the low prices following, that Select Committees of the House of Lords, and of the House of Commons, respectively, were appointed to inquire into the matter; as now we have a Royal Commission to inquire into the distress caused, not by abundant, but by deficient crops, and large importations, though by no means such low prices as during the period of great abundance.

1832.—The records show considerably higher than average temperatures during October, November, December (1831), and January (1832); a great excess of rain in October, and about average amounts in November and December, but a deficiency in January. February and March were rather under average as to temperature, with fairly average amounts of rain. In April the temperature was rather over, in May rather under, in June rather over, in July rather under, and in August about average. There was a considerable deficiency of rain in April, May, and July, and again in September, but a considerable excess in June and August. Of this season, Tooke and Newmarch say that the winter was open, the spring of medium forwardness, the summer unsettled to the end of July, then fine to the end of August, when heavy rains damaged the crops still out. Of the crops they say they were well harvested south of Yorkshire, and that the yield was abundant.

Thus this abundant crop was grown under the influence of a mild and rather wet winter, a spring of moderate characters, and a summer of only moderate temperatures, and with heavy rains excepting in July.

1833.—October, November, December, and February were for the most part considerably warmer than the average; but January and March were considerably colder, and April rather colder than the average. There had been a considerable amount of rain in October, and there was a great excess in February; but there was a deficiency in every other month from November to May inclusive. May was also unusually hot; June was hot with a rather high total of rain, but greatly due to a violent gale about the middle of the month; July was rather, and August and September were considerably, below the average as to mean temperature; but the fall of rain during the three months was below average. Tooke and Newmarch say that the winter was open and wet, the spring wet excepting part of March; May, and most of June, fine; July showery, and the autumn mostly favourable for maturing and harvesting the crops, which were rather thin on the ground, but yielded well.

Thus this second of the series of abundant wheat-crops was grown in a season characterised by a generally mild and moderately wet winter and early spring, excepting January and March, which were cold. The remainder of the spring, and the early summer, were hot and mostly dry, and the rest of the season upon the whole favourable. The result was a high yielding, but not bulky straw crop.

1834.—The mean temperature was higher than the average in every month from November 1833 to September 1834 inclusive, excepting in April, when the deficiency was not great. The excess was the most marked in the winter and in May, June, and July. November, December, and January were wet as well as warm; but February, March, April, and May were very dry, and June was scarcely average as to rainfall; in July there is a great excess indicated, which, however, was due to a tremendous storm, chiefly confined to London and twenty or thirty miles distant; in August there was again an excess, but in September a considerable deficiency. According to Tooke and Newmarch, the winter was mild and wet, the spring generally forward, the summer decidedly fine and dry, with high temperatures, and the autumn also fine; the wheat-crop remarkably abundant, got in well, of fine quality, and large yield.

This, which was one of the heaviest crops of wheat on record was, therefore, grown in a season warmer than usual almost throughout, but especially in the winter and in the spring, excepting April; and, after an excess of rain in the winter, there was a considerable deficiency for four months, to the end of May,again a deficiency in June, but afterwards heavy rains, though with high temperatures.

1835.—The mean temperatures were higher than the average in every month from November to September inclusive, excepting in March, which was close upon the average. There was a considerable excess of rain in February, March, May, and June, but a considerable deficiency in October, November, December, January, April, July, and August. Tooke and Newmarch observe that the winter was as open, and as much marked by an absence of snow and frost as the three preceding winters; that the spring was upon the whole favourable to the wheat-crops; the summer brilliantly fine till the last week in June, and the wheat of extraordinary bulk and luxuriance. At the close of June heavy rains and high winds laid the crops; but bright breezy weather in July stayed the damage, though much did not ripen well. The rest of the season was fine. The wheat-crops were got in in excellent order; but, though bulky, they were decidedly inferior in both yield and quality to those of 1834.

To sum up in regard to these four consecutive seasons of abundant wheat-crops: it is seen that they were characterised by mild and open winters, upon the whole mild springs, and average or warmer than average summers—especially the last two of the four. In each season there were individual months of considerably more than average fall of rain, sometimes earlier, and sometimes later, and accordingly influencing the bulk of the crop. But each season was characterised by less than the average fall of rain during several months of the growing period, and this was particularly the case in the season of 1834, the one of the most extraordinary productiveness.

We now come to those of the seasons selected for illustration which have occurred since the commencement of the Rothamsted experiments, and the characters of which are, therefore, more within our own knowledge and observation. Of these we will take first the seasons of high productiveness, and take them in chronological order.

1854.—November (1853) was about, but December considerably below, the average as to temperature, indeed very severe; and portions of January and February were also severe, with heavy snow in January; but still the four months, January to April inclusive, each showed higher than the average mean temperature. In October (1853) there had been a great excess of rain, but during each of the six months from seed-time to the end of

April there was a considerable deficiency, and in all only half the average fall, the total deficiency for the six months amounting to about 5½ inches. In May there was a considerable excess of rain, which was very beneficial to the crops after the long dry period. There was again a considerable deficiency in June and July, but an excess in August. As to temperature, May, June, and July were all below the average; and August only average. Of this season Tooke and Newmarch say—that May was cold and wet, June cold and ungenial, with less sun than usual, July not one day of summer-heat; harvest ten days or a fortnight later than usual. And of the crop they say—the largest yield per acre that has been known for years, the largest since 1834. Our own estimate of the crop over the United Kingdom was 35⅞ bushels, reckoned at 61 lbs. per bushel, the average of sixteen years being 28¼ bushels.

Thus, the crop of 1854, which was very abundant both in corn and straw, was, after a severe winter period, grown under higher than average temperatures during the earlier, but lower during the later, periods of growth; and with much less than the average fall of rain in every month from seed-time to harvest, excepting in May and August.

1857.—This was a season of much more than average productiveness of corn, but of only about average growth of straw, and it was characterised as follows:—The mean temperature of each of the six months, from November to April inclusive, varied little from the average; but May was 1·5, June 3·6, July 2·9, and August 4·9 degrees warmer than the average. There had been much less than the average fall of rain in October 1856, and in each of the seven months from November to May inclusive there was a considerable deficiency of rain, excepting in January, when there was an excess. The total deficiency during the seven months from seed-time to the end of May was about 5¼ inches. In June there was rather more than average, in July much less, but in August some excess.

Thus, this heavy corn- but not heavy straw-crop was obtained under the influence of about average winter and early spring, but high summer temperatures; and, as in other cases of high productiveness, there was here again much less than the average fall of rain from seed-time to harvest, the only months of any excess being January, June, and August.

1863.—The harvest of 1863, not only yielded in our own experimental wheat-field the most abundant crop since the commencement of the experiments in 1843–4, but it probably gave the highest average produce per acre over the country at large since 1834. With the exception of November (1862), which was unusually cold, every month from seed-time to the end of April was warmer than the average. The excess was in December 4·4, in

January 5·2, in February 3·4, in March 2·8, and in April 3 degrees. In October (1862) there had been a considerable excess of rain; but from that time to the end of May there was a considerable deficiency in every month excepting January, when there was an excess. The total deficiency in the seven months from November to May inclusive was more than 5 inches compared with the average. Thus, after an excess of rain in October, the winter and spring were not only unusually warm, but unusually dry, bringing the plant very early forward. May showed, however, rather lower, and June, July, and August only about, or but little higher than average temperatures. In June there was a considerable excess of rain, which, coming after such a long dry period, much aided growth, though it was sometimes so heavy as to lay the most forward and bulky crops. July and August were, on the other hand, considerably deficient in rain.

To sum up:—The conditions of season which gave the most abundant produce of both grain and straw throughout the thirty-six years of our experiments, and also much higher than average weight per bushel of grain, was characterised by an extremely mild winter and early spring, with much less than the average fall of rain during that period. The plant was thus brought early forward. Then came, in the early summer, a considerable amount of rain, after which there was a deficiency up to harvest. The temperature was only about the average in June and July, conducing to continued luxuriance rather than to early maturation; whilst August, the harvest month, was both warmer and drier than usual. The conditions were, therefore, those of a lengthened and almost unbroken course of gradual accumulation, with finally a favourable ripening period.

1864.—As has been seen, the crop of 1863 was probably the most abundant, both in corn and straw, of any among the thirty-six years of our observations—indeed the most abundant since 1834; and that of 1864, immediately succeeding it, is estimated to be only second to it in bulk and yield. October 1863 had been both warmer and drier than usual. Five out of the seven months, from November to May (1864) inclusive, were warmer than the average. The exceptions were January, which was only average, and February, which was 2·7 below average. With these prevailing higher than average temperatures during the winter and spring, there were nearly 4 inches less than the average fall of rain from seed-time to the end of May. The only month in which there was an excess was March, whilst in May there was only the average fall. June was rather below, July but little above, and August again rather below the average as to temperature; whilst in each of these three months there was much less than the average fall of rain.

Here again, then, the very large crop was produced under the influence of warmer than average weather in early winter and in spring; only moderate or even lower than average summer temperatures; but much less than the average fall of rain from seed-time to harvest; every month being considerably deficient, excepting May, which was average, and March, in which alone there was an excess.

1868.—After a favourable seed-time, the early winter of 1867–8 was very variable as to temperature, including some warm, but more stormy, wet, snowy, and frosty weather. From February, inclusive, to after harvest, the temperature was almost always above the average, and greatly so in May, June, and July; whilst, after a considerable excess of rain in January, there was, in each month from February to July inclusive, excepting in April, an unusual deficiency.

The period of growth was, therefore, almost throughout one of drought, with high temperatures throughout both spring and summer. The result was a very early harvest, a not bulky, but a high-yielding crop on good and well-farmed soils, but a deficient one on light and poorly-farmed land.

1870.—The autumn of 1869, though frequently cold, boisterous, and inclement, was upon the whole not unfavourable for getting in the seed. The winter and early spring were changeable, and upon the whole colder than the average. But from the beginning of April until harvest the weather was, with few exceptions of short duration, warmer than usual, with a great deficiency of rain. The combined heat and drought were even more extreme during the months of May, June, and July, 1868, than during the corresponding months in 1870; the mean temperature being notably higher in each of these months in 1868. But in 1870 the deficiency of rain commenced a month earlier, and was greater than in 1868.

After a by no means favourable winter, followed by prolonged spring and summer drought and heat, the wheat-crop of 1870 was deficient in straw, and also yielded less corn than that of 1868, but still considerably more than the average, a high proportion of corn to straw, and high quality of grain.

Thus, out of the six years of highest productiveness throughout the thirty-six seasons of our experiments, the three which gave the highest produce of all, and high produce of straw as well as corn, and also high quality of grain (1863, 1864, and 1854), were characterised by generally higher than average mean temperatures during the winter and early spring (excepting the early winter of 1853–4, which was severe), but generally only average, or lower than average, summer temperatures. Indeed, June 1854 was colder than June 1879. Each was also characterised by very much less than the average fall of rain from seed-time to harvest there being in no case an excess in more than two out of the nine months from November to July inclusive. The other three seasons of high productiveness, 1857, 1868, and 1870, though they gave less corn than the foregoing, and very much less straw, were, nevertheless, seasons of considerably more than average produce of corn, and of high quality of grain. These less bulky, but high-yielding crops were grown under more variable winter conditions as to temperature, but under much higher both spring and summer temperatures, especially those of 1868 and 1870; whilst, with the higher temperature there was, as in the cases with lower temperature and more abundant crops, much less than the average fall of rain from seed-time to harvest, one or two months only showing an excess.

We now come to the consideration of the seasons selected for illustrating the characters of low productiveness, namely, 1816, 1853, 1860, and 1879. We will first refer to the last three, which come within the period of our own observations, and then compare the characters of the extraordinarily unproductive season of 1879 with those of the also extraordinarily unproductive one of 1816.

1853.—The winter was very unseasonably warm and also wet. There had been a great excess of rain in October and November, and fully average amounts in December and January, causing floods, and much land intended for wheat remained unsown. From February to September, inclusive, every month was colder than the average, excepting May and June, which were about average; and the deficiency was greater in the spring than in the summer. In April there was a great excess of rain; in May there were heavy snow-falls; in June there was an excess of rain; in July a very great, and in August some, excess; and in September about an average amount. The breadth of land under wheat was much reduced, and the crop was reported to be far inferior, both in quantity per acre and in quality, to that of any season for many years past.

Thus the conditions under which this very inferior crop was grown were—that the early winter had been unseasonably wet and warm, the land being generally saturated with water, and in many cases flooded; the spring was unseasonably cold, and also wet; and the summer was also upon the whole colder than the average, and very wet.

1860.—From November (which was about average as to temperature) to May, inclusive, the months were alternately much colder and warmer than the average, May being warmer. But June, July, August, and September were all unusually cold and sunless for the period; very much more so than in 1853. There had been an excess of rain in October and November, but from that time till the end of April only moderate amounts, with, however, snow in February, March, and April. There was a great excess of rain in May, June, August, and September, and there was about an average amount in July. The harvest was very late. Wheat was in some localities not deficient in bulk, but generally very much damaged, yielding but a small proportion of grain, and that of very low quality.

The characteristics of this season, yielding a crop both late and much below the average, both in quantity and quality, were, then, a winter alternately very cold and very mild, and upon the whole wet, followed by a spring, summer, and autumn generally stormy, cold, wet, sunless, and unseasonable.

1879.—Of all the eleven months, from November to September inclusive, March alone showed about average mean temperature. Each of the others was colder than the average. The deficiency was in November 2·6, in December 5·5, in January 4·7, in February 0·5, in April 2·9, in May 4·1, in June 1·3, in July 3·5, in August 1, and in September 0·2 degree. Then as to the rainfall. There was an excess in every month of the eleven excepting December and March. In November the excess amounted to 1·05, in January to 0·59, in February to 2·32, in April to 0·90, in May to 1·36, in June to 2·39, in July to 1·12, in August to nearly 3 inches, and in September to 0·43 inch. The total excess over the period was more than 11 inches.

Thus, from seed-time to the harvest of 1879, there was a considerable deficiency of temperature, compared with the average, in every month excepting March. It is remarkable, however, that there was even a lower mean temperature in June 1854, a season of very great abundance, than in June 1879, the season of the worst crop known within the century. But it was by the continuity and excessive amount of the rainfall that the season of 1878–9 was especially characterised; the excess during the eleven months from November to September inclusive, being, as already said, more than 11 inches over the average; and the total amount was more than double that over the same period of some of the seasons of high productiveness.

It remains to compare the characters of the disastrous season of 1878–9, with those of 1815–16, to which period, by common consent, we must go back for a wheat-crop at all approaching in deficiency, both in quantity and quality, that of the season just past.

1816.—Each of the ten months from November 1815 to August 1816, inclusive, was colder than the average. The deficiency was—in November 4·3, in December 2·6, in January 0·3, in February 4·2, in March 1·7, in April 2·5, in May 3·2, in June 3·1, in July 4·6, and in August 4·6 degrees. The average deficiency over the ten months was 3·1 degrees; and the deficiency was the greatest in the months of more active growth and of maturation. Compared with 1878–9, December and

January (1815–16) were not nearly so cold, but November, February, and March were colder in 1815–16. The mean temperatures of April and May were rather the higher in 1816; but those of June, July, and August were considerably lower in 1816 than in 1879. In fact, there is no instance of so low a temperature prevailing throughout these three summer months, in any other of the 108 years, the temperature for which Mr. Glashier has given us the record. In each of the seven months, November 1815 to May 1816 inclusive, the fall of rain was only about, or not much over, the average; there being only one-third of an inch of excess compared with the average over that period; whilst, during the same months of 1878–9, there was an excess of more than 4¼ inches, and an excess compared with 1815–16 of nearly 4 inches. In June 1816 there was an excess, in July a great excess, but in August only a slight excess of rain; the total excess in the three summer months being only 2·34 inches, whilst in 1879 it was 6·3 inches. Over the whole ten months from November to August inclusive, 1815–16 showed only a total excess of 2·68 inches, whilst the same period of 1878–9 showed an excess of 10·6 inches over the average of 63 years; and for the first nine months of 1879 a higher rainfall is recorded than in the corresponding period of any year of the sixty-three. In September 1879 there was considerably more rain than in September 1816. But afterwards, with a very late harvest in both cases, there was a considerable excess in 1816, and a considerable deficiency in 1879; and it is stated that, in 1816, some wheat was still out when the winter snows began.

Thus, from seed-time to the end of May, the season of 1815–16, though materially colder than the average, did not include such a severe period as that of the winter of 1878–9; whilst the fall of rain was very little over average, and very much below that of 1878–9. From seed-time up to the end of the spring, therefore, the season of 1815–16 was more favourable than that of 1878–9 as to temperature, and much more favourable as to rainfall—indeed, not specially unfavourable. During the three summer months, however, the temperature of 1816 was extremely low, and much lower than the corresponding though still low period of 1879. And, with the very low temperature of the summer of 1816, there was at the same time an excess of rain, but by no means so great an excess as in 1879; but subsequently, there was not only low temperature, but excess of rain in 1816, much damaging, and often preventing the harvesting of the crop.

There can be little doubt, therefore, that the season of 1879 was, from seed-time to the end of the summer, worse than that of 1816. The latter suffered more from low temperature, but less from excess of rain during the summer. Both crops were, however, very late, and, for getting in the crop, the season of 1816 was much worse than that of 1879.

Having now pointed out the prominent characters as to temperature and rainfall of each of the fourteen seasons selected for illustration separately, it will be of interest, disregarding as much as possible the specialities of individual seasons, to consider the average character of classes of seasons, arranged according to the general character of their wheat crops. Accordingly, in Tables IV. V. and VI. the fourteen seasons are classified as stated below. There are given the average monthly mean temperatures and rainfall for each class, the difference between the result for each class and the average for a number of years, and the difference between the result for one class and another. The classes are as follows:—

Six years of high produce of both corn and straw; namely, 1832, 1834, 1835, 1854, 1863, and 1864.

Four years of high produce of corn, but not of straw; namely, 1833, 1857, 1868, and 1870.

Four years of very low produce; namely, 1816, 1853, 1860, and 1879.

Of course, the essential character of all averages is to eliminate extremes, and as the class of six seasons of high produce of both corn and straw includes individual seasons differing more widely from one another, both as to temperature and rainfall, than those within either of the other classes, the averages given in the table for that class cannot be taken as showing the character of the class without more of qualification than in the other cases. Admitting this, it will still be found that, taking considerable periods of the seasons—from seed-time to the end of April, and from the beginning of May to harvest, for example—the averages do clearly bear out the general conclusions to which the consideration of the individual seasons has led, in regard to the main characteristics of those periods.

The first class includes the six seasons out of the fourteen which gave the heaviest total produce, corn and straw together; and it is to be observed that it is those seasons of greatest luxuriance of growth, which have also given the most corn per acre.

Confining attention, in the first place, to the period of six months, from November to April inclusive, in only one of the six seasons which go to make the average, were there two months, and in four others there was only one month of the six, of in any material degree lower than average temperature, and in only one season (1854) was there a really severe winter

TABLE IV.—SUMMARY of TEMPERATURE of SELECTED SEASONS, CLASSIFIED according to the CHARACTER of their WHEAT CROPS.

Mean Results for each Class, &c.

MONTHS.	Six Seasons of much both Corn and Straw.	Four Seasons of much Corn, but not much Straw.	Four Seasons of Low Produce.	Average of 108 Years, 1771 to 1878.	Six Seasons of much Corn and Straw + or − Average of 108 Seasons.	Four Seasons of much Corn + or − Average of 108 Seasons.	Four Seasons of Low Produce + or − Average of 108 Seasons.	Six Seasons of much Corn and Straw + or − Four of much Corn.	Six Seasons of much Corn and Straw + or − Four of Low Produce.	Four Seasons of much Corn + or − Four of Low Produce.
MONTHLY MEAN TEMPERATURE AT GREENWICH.										
	°	°	°	°	°	°	°	°	°	°
October	51·4	50·1	50·1	49·6	+ 1·8	+ 0·5	+ 0·5	+ 1·3	+ 1·3	0·0
November	43·3	42·2	42·2	42·3	+ 1·0	− 0·1	− 0·1	+ 1·1	+ 1·1	0·0
December	41·4	39·5	38·7	39·2	+ 2·2	+ 0·3	− 0·5	+ 1·9	+ 2·7	+ 0·8
January	39·5	36·7	37·6	36·6	+ 2·9	+ 0·1	+ 1·0	+ 2·8	+ 1·9	− 0·9
February	39·3	40·2	35·4	38·7	+ 0·6	+ 1·5	− 3·3	− 0·9	+ 3·9	+ 4·8
March	42·4	40·8	40·0	41·1	+ 1·3	− 0·3	− 1·1	+ 1·6	+ 2·4	+ 0·8
April	47·4	47·0	43·7	46·1	+ 1·3	+ 0·9	− 2·4	+ 0·4	+ 3·7	+ 3·3
May	53·0	56·0	50·9	52·5	+ 0·5	+ 3·5	− 1·6	− 3·0	+ 2·1	+ 5·1
June	58·6	61·1	56·3	58·2	+ 0·4	+ 2·9	− 1·9	− 2·5	+ 2·3	+ 4·8
July	62·1	64·6	58·3	61·6	+ 0·5	+ 3·0	− 3·3	− 2·5	+ 3·8	+ 6·3
August	61·5	62·0	58·5	60·9	+ 0·6	+ 1·1	− 2·4	− 0·5	+ 3·0	+ 3·5
September	56·8	57·4	54·8	56·5	+ 0·3	+ 0·9	− 1·7	− 0·6	+ 2·0	+ 2·6
Average ..	49·7	49·8	47·2	48·6	+ 1·1	+ 1·2	− 1·4	− 0·1	+ 2·5	+ 2·6

TABLE V.—SUMMARY of RAINFALL of SELECTED SEASONS, classified according to the character of their WHEAT CROPS.

Mean Results for each Class, &c.

MONTHS.	Six Seasons of much both Corn and Straw.	Four Seasons of much Corn, but not much Straw.	Four Seasons of Low Produce.	Average of 63 Years, 1815–'77.	Six Seasons of much Corn and Straw + or – Average of 63 Seasons.	Four Seasons of much Corn + or – Average of 63 Seasons.	Four Seasons of Low Produce + or – Average of 63 Seasons.	Six Seasons of much Corn and Straw + or – Four of much Corn.	Six Seasons of much Corn and Straw + or – Four of Low Produce.	Four Seasons of much Corn + or – Four of Low Produce.
MONTHLY RAINFALL AT GREENWICH.										
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
October	2·89	2.09	2·91	2·8	+ 0·09	– 0·71	+ 0·11	+ 0·80	– 0·02	– 0·82
November	1·71	1·43	3·46	2·4	– 0·69	– 0·97	+ 1·06	+ 0·28	– 1·75	– 2·03
December	1·92	1·92	1·95	2·1	– 0·18	– 0·18	– 0·15	0·00	– 0·03	– 0·03
January	1·66	2·34	2·15	2·0	– 0·34	+ 0·34	+ 0·15	– 0·68	– 0·49	+ 0·19
February	1·19	1·41	2·01	1·5	– 0·31	– 0·09	+ 0·51	– 0·22	– 0·82	– 0·60
March	1·36	1·24	1·46	1·6	– 0·24	– 0·36	– 0·14	+ 0·12	– 0·10	– 0·22
April	0·66	1·24	2·24	1·7	– 1·04	– 0·46	+ 0·54	– 0·58	– 1·58	– 1·00
May	2·06	0·67	2·73	2·0	+ 0·06	– 1·33	+ 0·73	+ 1·39	– 0·67	– 2·06
June	2·17	1·41	3·81	1·9	+ 0·27	– 0·49	+ 1·91	+ 0·76	– 1·64	– 2·40
July	1·53	1·46	4·07	2·6	– 1·07	– 1·14	+ 1·47	+ 0·07	– 2·54	– 2·61
August	2·26	2·22	3·54	2·4	– 0·14	– 0·18	+ 1·14	+ 0·04	– 1·28	– 1·32
September	2·03	2·10	2·56	2·4	– 0·37	– 0·30	+ 0·16	– 0·07	– 0·53	– 0·46
Total	21·44	19·53	32·89	25·4	– 3·96	– 5·87	+ 7·49	+ 1·91	– 11·45	– 13·36

TABLE VI.—SUMMARY of RAINFALL of SELECTED SEASONS, classified according to the character of their WHEAT CROPS.

Mean Results for each Class, &c.

MONTHS.	Six Seasons of much both Corn and Straw.	Four Seasons of much Corn, but not much Straw.	Four Seasons of Low Produce.	Average of 55 Years, 1815–'69.	Six Seasons of much Corn and Straw + or − Average of 55 Seasons.	Four Seasons of much Corn + or − Average of 55 Seasons.	Four Seasons of Low Produce + or − Average of 55 Seasons.	Six Seasons of much Corn and Straw + or − Four of much Corn.	Six Seasons of much Corn and Straw + or − Four of Low Produce.	Four Seasons of much Corn + or − Four of Low Produce.
NUMBER OF DAYS ON WHICH 0·01 INCH OR MORE FELL AT GREENWICH.										
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
October	17	15	16	14	+ 3	+ 1	+ 2	+ 2	+ 1	− 1
November	11	10	17	13	− 2	− 3	+ 4	+ 1	− 6	− 7
December	15	14	19	12	+ 3	+ 2	+ 7	+ 1	− 4	− 5
January	14	16	18	12	+ 2	+ 4	+ 6	− 2	− 4	− 2
February	11	12	15	11	0	+ 1	+ 4	− 1	− 4	− 3
March	12	12	16	12	0	0	+ 4	0	− 4	− 4
April	7	14	15	11	− 4	+ 3	+ 4	− 7	− 8	− 1
May	12	5	14	11	+ 1	− 6	+ 3	+ 7	− 2	− 9
June	11	8	18	11	0	− 3	+ 7	+ 3	− 7	−10
July	8	9	18	11	− 3	− 2	+ 7	− 1	−10	− 9
August	10	10	18	11	− 1	− 1	+ 7	0	− 8	− 8
September	12	11	15	12	0	− 1	+ 3	+ 1	− 3	− 4
Total	140	136	199	141	− 1	− 5	+ 58	+ 4	− 59	− 63

month. With these few exceptions every other month of the six within each of the six seasons was either about average or over average, and in many cases very much over average as to temperature. Then as to the rainfall over the same period. In two of the seasons there were two months, and in two there was only one month, with any considerable excess of rain; whilst in the other two there was a deficiency in every month of the six. There were, therefore, in each of the six seasons, four, five, or six of these six months considerably drier than the average.

Next, as to the three months of May, June, and July. In two out of the six seasons, each of the three months was warmer than the average; in two each was colder than the average; and in the remaining two there were warmer and colder months, giving about average mean temperatures. As to the rain of these three months, in one out of the six years there was an excess in two of the three months, in four years in only one of the three, and in the other in neither month, an excess of rain. In one only of the six years was the total rain of the three months over the average; though, in three of the six seasons there was an excess in August.

With these explanations as to the elements making up the averages for the six seasons, it is to be observed that their average mean temperature was higher than that of 108 years, in every month of the twelve; but that the excess was very much greater in the months prior to May than in May and afterwards. In fact, the excess of mean temperature, taking the average of these six seasons of greatest productiveness of both corn and straw, is, notwithstanding the coldness of one or two winter or spring months in individual seasons, very much greater before May than afterwards, and it is, notwithstanding the high summer temperature of two of the years, quite insignificant afterwards. Turning now to the average rainfall: there is less than the average amount in nine months out of the twelve, and in the other three the excess is quite insignificant. It is remarkable, too, that the longest period of deficiency is from seed-time to the end of April; the period during which the temperatures were at the same time more in excess of the average. Further, the only month of any important amount of average excess is June; but Table VI. shows that there was, even in that month, not more than the average number of rainy days; whilst, of course, the higher temperatures, and the growth of the crops, at that period, would tend to counteract any otherwise evil effects from an excess.

Upon the whole, then, the seasons of highest productiveness of all were characterised by higher than average temperatures during most of the winter and the early spring. Some were considerably warmer during the summer also, but the majority were characterised by but little higher, or even lower, than average temperatures in the summer. There was also a prevailing deficiency of rain in the winter and spring, but a less marked deficiency in the summer.

The second class includes four seasons of high produce of corn, but of small produce of straw; and these seasons of high yield gave, on the average, less corn per acre than the seasons of greater total bulk of produce. Here, again, we have higher than average mean temperatures in every month but November and March, and then the deficiency was quite insignificant. But, in these seasons of comparatively small total produce, but of high yield of grain, the distribution of the excess of temperature is exactly the opposite of that observed in the case of the seasons of heaviest gross produce. We have now comparatively insignificant excess of temperature in each month prior to May, but a considerable excess in May and the subsequent months, to harvest. Then as to the rainfall: the only month of the twelve in which there is any excess above the average is January; whilst it is in May, June, and July, the months of excess of temperature, that the deficiency is by far the most marked. It is in these three months too that the number of rainy days is the most below the average.

In the cases, then, of small produce of straw, but of high proportion of corn to straw, the result was associated with little more than fairly average conditions as to temperature during the early stages of development of the plant, but with a considerable excess during the period of active above-ground growth, and of maturation. There is, at the same time, though a considerable total deficiency of rain, a much more marked deficiency during the periods of more active above-ground growth, and of ripening, than during the earlier stages.

The third class of seasons, that including four of unusually low produce, shows very marked differences from either of the foregoing. The averages show an actual deficiency of temperature in ten months out of the twelve; and in only one from seed-time to harvest was there an average excess of any importance, namely, in January. The deficiency of temperature was also more marked in the spring than in the winter, and more in the summer than in the spring. With this great deficiency of average temperature almost throughout, we have also, almost throughout, an excess of rain; and the excess is very much the greater in April and afterwards up to harvest than previously. The number of rainy days is also greatly in excess, especially in the summer months. Very low productiveness was, then, associated with both low temperatures and excess of rain, especially during the periods of more active above-ground growth and ripening.

An examination of the last three columns of the Tables will bring to light the differences, not between each class of seasons and the average, but between class and class.

Comparing with one another the seasons of both greatest total produce and highest produce of corn also, with those of comparatively low total produce, but of high yield of grain, it will be seen how prevailingly higher was the average mean temperature from seed-time to April inclusive, how much lower it was in May and afterwards, and also how much greater was the fall of rain during May and afterwards, in the seasons of high total produce, than in those of high corn only. The last two columns, again, show in a striking manner the differences as to temperature and rainfall which distinguish, in the one case the seasons of high produce of both corn and straw, and in the other those of high produce of corn but not of straw, from the seasons of unusually defective produce.

From the foregoing review and comparison of a number of seasons of much more than average productiveness, and of some of the greatest deficiency within a period of sixty-four years, it would appear that mildness, and comparative dryness, of at any rate considerable portions of the winter and early spring, favouring root development, that is, an extended possession of the soil by the plant, and a somewhat early start, have been the characteristics of the most productive seasons. These conditions fulfilled, prior to the period of more active above-ground growth, some of the most bulky, and at the same time the most abundant grain crops, ripened under considerably higher than average summer temperatures also; but more of them ripened in summers of scarcely over, or even of under, average mean temperatures; and with, at the same time, but little, if any, less than the average fall of rain during that period. Indeed, the facts show that, with those favourable early conditions, an abundant, and also high-yielding, crop may be obtained with only fairly average, or even under average, summer conditions. But there can be little doubt that, when high summer temperatures, without excess of rain, do succeed upon the favourable conditions of early growth, and of plant, above described, the proportion of grain yielded by the bulky crop will be the greater. It happens, however, that the two both bulky and high-yielding crops which matured in the warmer than average summers were the produce of seasons before the period of our own observations. The less bulky, and somewhat less abundant in grain, but still high-yielding crops have, on the other hand, generally had less favourable conditions for winter root-development, and for early growth in spring, but have been developed under the influence of considerably higher than average summer temperature, with, at the same time, deficiency of rain almost throughout, and a considerable deficiency during the summer months.

The seasons of unusually deficient wheat-crops, on the other hand, have been characterised by severe, or at any rate very changeable, winter and spring conditions, with, at the same time, generally an excess of rain during those periods, frequently saturating the soil, causing much drainage, and discouraging root-development, and early growth in spring. But the more striking characteristic of the bad seasons is a great deficiency of average temperature, and especially a great excess of rain, from the period of active above-ground growth until harvest. The season which gave the extremely deficient crop of 1816 was characterised much more by unusually low temperatures throughout, and especially during the summer months, than by any marked excess of rain excepting during those summer months, and afterwards. The probably even still worse season of 1878–9, though very cold in the winter, was by no means so defective in temperature throughout the spring and summer months as 1816; but there was a great excess of rain, almost throughout the winter, spring, and summer, and a greater excess in the summer than in 1816, though much less afterwards. In a word, the crop of 1816 suffered more from low temperature than excess of rain, and that of 1879 much more from an excess of rain than from low temperature, until the middle of the autumn, after which 1816 continued wet, and 1879 became dry.

Lastly, it would appear that any defect of our climate in appropriateness for the production of full and well-matured wheat-crops is more connected with an excess of rain, and consequent wetness of soil and humidity of atmosphere, than with any deficiency of average summer temperature.

II.—THE SEASON OF 1878–79, AND THE EXPERIMENTAL WHEAT-CROPS AT ROTHAMSTED.

Having illustrated the characters of a number of seasons of high and of low productiveness, and especially of the wretched one of 1878–9, by reference to independent records, we now turn to a consideration of the characters of that season at Rothamsted, and of its effect upon the continuous wheat-crops there.

For twenty-seven years (1853–79 inclusive) the rainfall at Rothamsted has been measured by means of a gauge of one-thousandth of an acre area (6 feet × 7 feet 3 inches), and also by an ordinary 5-inch funnel-gauge, which had been in use some time previously.

The amount of the rainfall passing through 20 inches, 40 inches, and 60 inches of soil and subsoil, in their natural state of consolidation, has also been determined for a number of years; and the drainage waters so collected have frequently been analysed. These "*drain-gauges*," also each of one-thousandth of an acre area, were constructed by digging down, and undermining the soil, putting iron plates drilled with holes underneath, and then building round the square of undisturbed soil in brick and cement. Reference to the amounts of water passing through these *drain-gauges* will be made further on.

The following Table (VII.) shows the rainfall in inches, in each of the twelve months from October 1878 to September 1879 inclusive, as measured by both the large and the small rain-gauge above referred to. It also shows the rainfall recorded, for the same period, at four stations which may be said roughly to be north, south, east, and west of Rothamsted; namely, Bedford, Blackheath, Cambridge, and Oxford. For each place the number of days in each month when 0·01 inch, or more, fell, is also given.

It will be observed that the registries of the large and the small gauge at Rothamsted do not agree very closely during the individual winter months. This is chiefly accounted for by the accumulation or drifting of snow in the large gauge, and perhaps some loss of snow in the small gauge. During the other months the large gauge generally registers slightly more than the small; in those cases chiefly owing to measurable quantities of mist, fog, hoar-frost, &c., being frequently condensed on its large surface when none was collected in the small gauge, or the quantities were too small for measurement.

But the remarkable fact brought out by the Table is, that both the amount of rain, and the number of days on which 0·01 inch, or more, fell, were greater, and in some cases much greater, at Rothamsted than at either of the other stations; and the excess was the most marked in the summer months. Taking the whole twelve months, and adopting the mean of the two Rothamsted measurements, the fall was 8·38 inches more than at Bedford, 6·73 more than at Blackheath, 6·12 more than at Cambridge, and 7·18 more than at Oxford.

The actual amount of fall is not only very large, but it is in excess compared with the average in almost every month, and in the summer months especially very greatly so. Out of the 92 days of May, June, and July, more than 0·01 inch fell at Rothamsted on 65, leaving only 27 days without any rain, or with less than that amount; and, among the other places quoted, the

Table VII.—Rainfall in Inches, and Number of Days on which 0·01 inch, or more, fell, at Rothamsted, Bedford, Blackheath, Cambridge, and Oxford. Twelve Months, October, 1878, to September, 1879, inclusive.

	Rothamsted.			Bedford.	Blackheath.	Cambridge.	Oxford.
	Large Gauge.	Small Gauge.	Mean.				
Rainfall in Inches.							
October 1878.. ..	2·99	2·99	2·99	2·10	1·80	1·92	3·11
November „	4·55	4·73	4·64	3·50	3·53	4·66	2·28
December „	1·60	1·57	1·59	1·46	1·32	1·09	1·51
January 1879.. ..	2·85	2·46	2·66	2·25	2·47	1·98	3·00
February „	3·80	3·74	3·77	2·90	3·95	2·75	3·31
March „	1·18	1·09	1·13	1·00	0·70	0·88	0·88
April „	2·79	2·61	2·70	1·80	2·64	2·18	2·45
May „	3·48	3·46	3·47	3·25	3·37	3·32	2·71
June „	5·55	5·49	5·52	4·35	4·16	5·22	4·54
July „	4·24	4·17	4·20	4·20	3·62	3·49	3·38
August „	6·56	6·47	6·52	4·50	5·12	5·92	5·05
September „	3·13	3·07	3·10	2·60	2·88	2·76	2·89
3 months, Oct.–Dec.	9·14	9·29	9·22	7·06	6·65	7·67	6·90
3 months, Jan.–Mar.	7·83	7·29	7·56	6·15	7·12	5·61	7·19
3 months, April–June	11·82	11·56	11·69	9·40	10·17	10·72	9·70
3 months, July–Sept.	13·93	13·71	13·82	11·30	11·62	12·17	11·32
12 months..	42·72	41·85	42·29	33·91	35·56	36·17	35·11
Number of Days on which 0·01 Inch or more fell.							
October 1878.. ..	22	21	21	14	12	15	15
November „	22	23	23	17	15	21	16
December „	16	16	16	12	14	17	10
January 1879.. ..	13	13	13	7	10	12	9
February „	23	23	23	18	21	23	22
March „	14	14	14	10	14	17	13
April „	20	19	19	14	18	21	16
May „	18	18	18	16	17	19	16
June „	26	26	26	24	18	26	27
July „	21	21	21	22	18	22	19
August „	18	17	18	15	19	17	17
September „	14	14	14	14	14	13	15
3 months, Oct.–Dec.	60	60	60	43	41	53	41
3 months, Jan.–Mar.	50	50	50	35	45	52	44
3 months, April–June	64	63	63	54	53	66	59
3 months, July–Sept.	53	52	53	51	51	52	51
12 months..	227	225	226	183	190	223	195

number of the so-reckoned rainy days in those three months was exceeded only at Cambridge, though the total amount of rain there was less. In the night of August 2–3, a thunder-storm of great severity occurred, during which 3 inches or more of rain fell within a very few hours. With such a season we could obviously expect nothing but disaster to the wheat-crop; and from the comparisons given we should be prepared to find that the injury was greater at Rothamsted than in many other places.

The next Table (VIII.) shows the produce on some selected plots in the permanent wheat-field at Rothamsted in 1879, compared with the average on the same plots, and with the same manures every year, over the previous twenty-seven years:—

TABLE VIII.—PRODUCE of WHEAT on selected PLOTS at ROTHAMSTED, in 1879, compared with the AVERAGE of 27 YEARS.

	Dressed Corn.				Straw per Acre.	
	Quantity per Acre.		Weight per Bushel.			
	Average 27 Years, 1852–'78.	1879.	Average 27 Years, 1852–'78.	1879.	Average 27 Years, 1852–'78.	1879.
	Bushels.	Bushels.	lbs.	lbs.	Cwts.	Cwts.
Plot 3. Unmanured	13½	4¾	57·9	52·5	11¾	6¾
Plot 2. Farmyard-Manure	34⅛	16	60·1	56·8	32¾	20
Plot 7. Mineral manure and 400 lbs. ammonia-salts	33¼	16¼	59·5	56·7	33¾	26⅞
Plot 8. Mineral manure and 600 lbs. ammonia-salts	36⅞	20½	59·2	56·5	40⅜	37¼
Plot 9. Mineral manure and 550 lbs. nitrate soda	38¼*	22	59·2*	56·5	43⅛*	38¾

* Average of 24 years only instead of 27, as the exact manures stated were not applied to Plot 9 during the first 3 years of the 27.

We shall have to consider further on † whether, or in what degree, there was a tendency to diminished or to increased produce on these several plots from year to year due, irrespectively of the influence of season, to gradual exhaustion on the one hand, or to accumulation by the continuous application of the respective manures on the other. It will be sufficient here to call attention to the great deficiency, both in the quantity and the quality of the produce, in 1879, compared with the average, on every one of the plots, whether under conditions as to manuring tending to exhaustion or to accumulation.

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† In a sequel to this paper, which will probably be published in the next number of this 'Journal.'

It will be observed that the greatest proportional deficiency of corn was without manure, and with farmyard-manure; and that the deficiency was the less the higher the artificial manuring. Without manure, there certainly has been a gradual decline of produce from exhaustion; but it is remarkable that there were no less than nine other plots which, as well as the unmanured plot, gave less than 5 bushels of dressed corn in 1879.

The defect in weight per bushel of the dressed corn was great under all the conditions cited; but it was considerably greater without manure than with any of the selected manures.

Lastly, great as was the deficiency in the produce of corn, and in the weight per bushel of the dressed corn, under all the conditions, the proportional deficiency of straw was very much less. Indeed, it was but small with the higher artificial manuring.

It may be said that, from the beginning to the end of the season, the weather fought against the crop. In every month, from seed-time to harvest, excepting in March, the mean temperature was below, and frequently very much below, the average; and the total rainfall was more than $1\frac{1}{2}$ time as much as the average. The winter was very cold and also wet, so that the soil was saturated with water, and there was nothing to tempt the roots to spread, or to penetrate deeply. The low temperature and the great excess of rain in every subsequent month (except March) perpetuated this condition. The above-ground development was, therefore, also weak and unhealthy. Thus, the plant, which luxuriates in a comparatively dry soil and climate, passed its whole existence under exactly opposite conditions; and the result was only what was to be expected.

It has of course long been known that an excess of wet is injurious to the wheat-crop; but it is only comparatively recently that one at least of the material causes of the adverse influence has been clearly made out: namely, the great loss of nitrogen carried off by drainage in the form of nitrates.

In a paper published in this 'Journal' in 1856, Professor Way showed by the analysis of the drainage-waters from several soils, of different description, and differently manured, that whilst in such waters scarcely any ammonia was to be found, there was a variable and sometimes a very large amount of nitric acid, which he considered in all probability due to the oxidation of the nitrogenous organic matter of manures. Judging, however, from the results he had obtained, showing the power of soils to absorb ammonia, he was unwilling to believe in the conversion of ammonia into nitric acid within the soil. He further said that, considering how very great in some cases the quantities of nitric acid in the drainage-waters were—"we might be seriously impressed with the significance of the fact, were it not that we know that these waters are extreme instances, and that in all probability such a loss rarely if ever occurs in ordinary farming." And, he goes on to say that Mr. Paine, the drainage-water from whose soil had yielded so much nitric acid, was in the habit of using on his land large quantities of such substances as hair, horn shavings, woollen rags, &c., to which in all probability this large quantity of nitric acid is to be referred.

In our own experiments we had for many years found, especially in the case of grain-crops, that, of the nitrogen supplied in manure, a large proportion remained unrecovered in the increase of produce. It was found that when a given amount of nitrogen was supplied year after year, and the same description of crop was grown for a series of years in succession, generally less than half as much as had been supplied was recovered in the increase of crop. It was further found that, if the application of the nitrogenous manure were discontinued, only a very small proportion of the missing amount of nitrogen would be recovered each year in the succeeding crops.

At first we were disposed to consider that this loss of nitrogen of manure might, in part at least, be explained by reference to the vital actions of the plant itself, as it had been concluded by various experimenters that plants evolved nitrogen by their leaves during growth. But, reference to the brief history of the progress of knowledge on the subject given in our paper—"On the Growth of Barley for Twenty Years in Succession on the same Land"—(this 'Journal,' vol. ix., S.S., part 2, pp. 331 *et seq.*) will show that, in 1861, we had come to rely much more on accumulation within the soil, and on loss by drainage, to account for the missing amount of the nitrogen of manure; and that, as more and more evidence on these points was forthcoming, we attributed more and more of importance to drainage as a source of loss.

In the autumn of 1866, finding that Dr. Voelcker was desirous to investigate the question of land drainage, we gladly provided him with samples of the drainage-water from the differently manured plots in the experimental wheat-field, and also with full particulars of their history for the purposes of inquiry. The samples were collected at five different periods, and Dr. Voelcker gave a summary of the results of complete analyses of 65 samples of such drainage-waters of accurately known history, in a paper in the 'Journal of the Chemical Society of London' in 1871 (vol. xxiv., p. 276); and he gave the results more in detail, and with more of reference to their agricultural bearings, in a paper "On the Composition of Waters of Land Drainage," published in this 'Journal' in 1874. Dr. Voelcker determined not only the ammonia and the nitric acid in the drainage-waters, but also the whole of the mineral constituents.

Dr. Frankland also, at his own request, was supplied with numerous samples, not only of the drainage-waters from the different plots of the permanent wheat-field, but of those collected at the depths of 20, 40, and 60 inches respectively, from the "*drain-gauges*" already described; and also of the rain-water collected in the large gauge at Rothamsted. In all he analysed nearly 70 samples of rain-water, and more than 100 of drainage-waters so collected. He determined in them the organic carbon, the nitrogen in the different forms of combination in which it existed, and the chlorine. His results are published in full in the Sixth Report of the Rivers Pollution Commission, presented to Parliament in 1874. In that Report we have a very complete history of the waters of Great Britain, both above ground and under ground. We have the composition of the rain, the changes it undergoes in passing over or through various geological strata, and its condition as it appears again in rivers and springs.

The dates of collection of the samples of drainage-waters analysed by Dr. Voelcker ranged from December 1866 to December 1868; and those of the rain and drainage-waters analysed by Dr. Frankland from January 1868 to February 1873. More recently, the investigation has been continued in the Rothamsted Laboratory, and we have now a large number of results, which will be made the subject of a paper very shortly. In the meantime it will be sufficient for our present purpose to draw some illustrations from the already published results of Dr. Voelcker and Dr. Frankland.

At the conclusion of our paper "On the Effects of the Drought of 1870" (vol. vii., S.S. part 1, of this 'Journal'), we were enabled, by the courtesy of Dr. Voelcker and Dr. Frankland, none of whose results were then published, to point out how very large might be the loss of nitrogen from the land in the winter after the application of ammonia-salts in the autumn. And in our paper on the "Growth of Barley for Twenty Years in Succession on the same Land," in this 'Journal,' vol. ix., S.S., part 2, p. 334 *et seq.*, 1873, will be found tabular summaries of their results, and also a discussion of them.

In the following Table (IX.) is given a summary of some of the results of Dr. Voelcker and Dr. Frankland, in a different form from that above referred to. The object of the arrangement now adopted is, not only to indicate how great may be the loss suffered by the passing away of the nitrogen of manures in the form of

TABLE IX.—COMPOSITION of the DRAINAGE-WATER collected at different PERIODS of the SEASON, from PLOTS differently manured; BROADBALK FIELD, ROTHAMSTED; WHEAT every YEAR, commencing 1844.

Nitrogen as Nitrates and Nitrites, per 100,000 parts of Drainage-water.
Abstract of Dr. Voelcker's, and Dr. Frankland's Results.

		Ammonia-salts Autumn Sown, Nitrate Soda Spring Sown.			
		From Autumn Sowing to Spring Sowing.		From Spring Sowing to next Autumn Sowing.	
		Number of Collections.	Nitrogen per 100,000 Drainage.	Number of Collections.	Nitrogen per 100,000 Drainage.
Plot 5.	Mixed mineral manure alone	7	0·622	4	0·067
Plot 6.	Mixed mineral manure, and 200 lbs. ammonia-salts = 41 lbs. nitrogen	7	1·242	4	0·082
Plot 7.	Mixed mineral manure, and 400 lbs. ammonia-salts = 82 lbs. nitrogen	7	2·182	4	0·146
Plot 8.	Mixed mineral manure, and 600 lbs. ammonia-salts = 123 lbs. nitrogen	7	2·737	4	0·237
Plot 9.	Mixed mineral manure, and 550 lbs. nitrate-soda = 82 lbs. nitrogen	6	1·019	4	2·066

nitrates in the drainage, but to show how much greater is the loss during the winter than during the later periods of the season, when the manures have been autumn-sown.

The results in the Table relate to a period when the ammonia-salts were applied to the plots in question in the autumn, and the nitrate of soda only in the spring. In the first division is given the average composition of all the drainage-waters collected between the date of sowing the ammonia-salts in the autumn and that of sowing the nitrate in the spring; and in the second division the average of those collected after the sowing of the nitrate, and before the next autumn sowing.

Looking to the first division, relating to the samples collected during the winter, after the autumn sowing of the ammonia-salts, and comparing the results of plot 5 with mineral manure without ammonia-salts, with those of plots 6, 7, and 8, which had the same mineral manures, but with more and more of ammonia-salts in addition, it is seen that there was, not only much more nitrogen as nitric acid in 100,000 parts of the drainage-waters where ammonia-salts were applied than where they were not, but that there was a gradual increase in the amount thus drained away and lost, with the increase in the amount of ammonia-salts applied.

Comparing the figures relating to the same plots in the second division with those in the first, it will be noticed how very much less, indeed how very small, is the quantity of nitrogen as nitrates in a given quantity of the drainage-water collected after the conclusion of the winter period. Not only have the autumn-sown manures already been subject to a great loss during the winter, but vegetation is now more active, and more and more rapidly takes up and utilises the nitrates, and so serves to arrest their passage downwards. Further, with the increasing growth, and the increasing temperature, evaporation is increased, and the proportion of the rainfall which drains away is diminished. In fact, so far as can be judged from the data at command, the amount of water passing through the soil will, in ordinary seasons, be several times as much during the first four or five months after autumn-sowing and before the commencement of active above-ground growth, as afterwards to harvest. In the case of the autumn-sowing of the ammonia-salts there is, therefore, not only a much larger quantity of nitrogen as nitrates in a given quantity of drainage-water, but there is also a much larger quantity of water passing as drainage, during the winter than afterwards.

Lastly in regard to the results relating to the autumn-sown ammonia-salts, it will be observed that although the quantity of nitrogen as nitrates in a given quantity of the drainage-water collected after the winter, and after the commencement of more active growth, is very small, it is, as in the case of the samples collected during the winter, and sooner after the application, the greater, the greater the amount of ammonia-salts applied.

We have yet to notice the results obtained from the plot manured with nitrate of soda, which was always applied in the spring, and generally between the middle and the end of March. It is seen that the drainage from this plot was much richer in nitrates after the application of the nitrate in the spring than it was during the winter before the fresh application. Still, considering the great solubility of the nitrate, the little power of the soil to retain it, the fact that a crop had been grown and removed since the previous application, and the great quantity of drainage passing during the winter, the average amount of nitrogen as nitrates in the samples collected in the autumn and winter months is greater than would be expected compared with that from the plots manured with the ammonia-salts in the autumn. Nor is the average amount in the drainage collected after the application of the nitrate so high as might be expected; though the amount has been found to be very high in individual cases of drainage collected soon after the spring dressing.

Lastly, to facilitate the appreciation of the significance of the results given in the Table, it may be observed that, for every inch of rain passing beyond the reach of the roots, and containing one part of nitrogen as nitrates per 100,000 parts of water, there will be a loss of rather more than 2¼ (2·26) lbs. of nitrogen per acre; corresponding to about 11 lbs. of the "ammonia-salts," or to about 14½ lbs. of nitrate of soda. And, as illustrating how very great may be the loss when heavy rain and much drainage follow soon after the application of heavy dressings of ammonia-salts or nitrate of soda, it may be mentioned that one sample of drainage-water collected early in January 1872, after the application of 600 lbs. of ammonia-salts early in November, was found by Dr. Frankland to contain so much nitrogen as nitrates as to represent a loss of 18 lbs. of nitrogen per acre, corresponding to about 86 lbs. of the "ammonia-salts," or to about 114 lbs. of nitrate of soda, provided an inch of rain had passed away as drainage of that strength; which, however, was probably not the case. Again, in one case of the Rothamsted analyses, the drainage-water collected on April 7th from the plot which had been dressed with 550 lbs. of nitrate of soda on March 10, contained so much nitrogen as nitrates as to represent a loss of about 15½ lbs. of nitrogen per acre, corresponding to about 76 lbs. of the "ammonia-salts," or to about 100 lbs. of nitrate of soda, provided that (which again was probably not the case) an inch of rain had passed as drainage of that strength.

It should be added that, besides nitrogen as nitrates and nitrites, land drainage-waters always contain more or less as ammonia or as organic nitrogen, but the quantity passing away in these forms is quite insignificant compared with that lost as nitrates.

In consequence of the very conclusive evidence of the great loss by drainage of the nitrogen of ammonia-salts applied in the autumn, especially in wet winters, it was decided, in the autumn of 1872, to devote one plot in the experimental wheat field to the application of the ammonia-salts in the spring. Accordingly, plot 15, which had for many years been manured with approximately the same mineral manures, and approximately the same amount of nitrogen, as plot 7, was selected; and, from that time, precisely the same mineral manures, and precisely the same amount of ammonia-salts were applied to plot 15 as to plot 7. To both plots the mineral manures were, as before, applied in the autumn; to plot 7 (as to all the other ammonia-plots), the ammonia-salts also were applied in the autumn, but to plot 15 they were not applied until the spring. For the five crops, from 1873 to 1877 inclusive, this arrangement was continued. It happened that four out of the five seasons were wetter than the average, and especially during the winter months. The consesequence was that, in the two wettest seasons the result was very much against the autumn sowing; in two less excessively wet ones it was about equal; and, in the season of 1874 alone, the winter of which was dry, it was very decidedly in favour of autumn sowing. After the harvest of 1877, therefore, it was decided that plot 7, and all the other plots which had hitherto received ammonia-salts in the autumn, should not receive them until the spring, and that, for comparison with plot 7, plot 15 should now receive its ammonia-salts in the autumn.

The following Table (X.) shows the bushels of corn, and the weight of straw, and of total produce, obtained in each of the seven years, from 1873 to 1879 inclusive, by autumn sowing, and by spring sowing, respectively, of the ammonia-salts.

TABLE X.

SEASONS.	Dates of Sowing Ammonia-salts.		Corn, Straw, and Total Produce per Acre.					
			Corn.		Straw.		Total Produce.	
	Autumn.	Spring.	Autumn Sown.	Spring Sown.	Autumn Sown.	Spring Sown.	Autumn Sown.	Spring Sown.
			Bushels.	Bushels.	lbs.	lbs.	lbs.	lbs.
1873	Oct. 18	Mar. 25	22	32⅝	2021	3079	3344	5031
1874	,, 28	,, 19	39⅜	29⅛	4645	2776	7094	4588
1875	,, 23	,, 23	25⅞	25½	3422	3204	5110	4915
1876	,, 30	,, 24	23½	25½	2212	2428	3793	4083
1877	,, 17	Apr. 11	19⅞	33⅛	1835	2788	3048	4795
1878	Nov. 3	Mar. 14	22⅛	31¼	3071	4952	4486	7017
1879	Oct. 15	,, 10	5⅜	16¼	906	3012	1275	4063
Averages	..	..	22½	27¾	2587	3177	4021	4927

It will be observed that, in 1874 alone, was the result decidedly in favour of autumn sowing. In 1873, 1877, 1878, and 1879, it was decidedly against autumn sowing; whilst, in 1875 and 1876, the difference was immaterial.

In Table XI. (page 36) is shown :—

1. The increase or diminution of produce by spring sowing.
2. The rainfall in each season, from the date of autumn sowing to that of spring sowing, and from that of spring sowing to the end of June, as measured by the large gauge at Rothamsted.
3. The amount of drainage passing through 60 inches of soil in the "drain-gauge" during the same periods.

As already said, we have no means of gauging the amount

TABLE XI.

SEASONS.	Dates of Sowing Ammonia-salts.		Produce More (+) or less (−) by Spring Sowing.			Rainfall, Large Gauge.		Drainage (60 Inch Drain Gauge).	
	Autumn.	Spring.	Corn.	Straw.	Total.	From Autumn to Spring Sowing.	From Spring Sowing to end of June.	From Autumn to Spring Sowing.	From Spring Sowing to end of June.
			Bushels.	lbs.	lbs.	Inches.	Inches.	Inches.	Inches.
1873	Oct. 18	Mar. 25	$+ 10\frac{5}{8}$	+1058	+1687	18·53	4·39	11·45	0·05
1874	„ 28	„ 19	$- 10\frac{1}{4}$	−1869	−2506	7·05	5·12	2·89	0·25
1875	„ 23	„ 23	$- 0\frac{3}{8}$	− 218	− 195	10·55	7·89	5·21	0·51
1876	„ 30	„ 24	+ 2	+ 216	+ 290	12·17	6·12	10·14	1·94
1877	„ 17	Apr. 11	$+ 13\frac{1}{4}$	+ 953	+1747	22·01	4·90	15·78	0·74
1878	Nov. 3	Mar. 14	$+ 9\frac{1}{8}$	+1881	+2531	11·17	12·30	8·11	5·96
1879	Oct. 15	„ 10	$+ 10\frac{7}{8}$	+2106	+2788	15·05	12·86	13·09	4·95
Averages	..	..	$+ 5\frac{1}{4}$	+ 590	+ 906	13·79	7·65	9·52	2·06

of drainage from the different plots in the experimental wheat-field. But the record of the amount of the rain passing through 60 inches of soil and subsoil in one of the "drain-gauges" described at p. 26, will at any rate give some idea of the characters of the different seasons in regard to drainage. As the soil of the "drain-gauge" is without vegetation, the amounts of drainage passing through it during the winter, that is from the date of autumn sowing to the date of spring sowing, will doubtless more nearly represent the relative, and in some degree the actual, amounts passing through the soil of the wheat-field during that period than afterwards. But, after active vegetation has commenced, the drainage would doubtless be proportionally less in the wheat-field than through the bare drain-gauge soil.

From what has been shown in the former part of this paper, it will be obvious that the exact differences in the amount of produce obtained by autumn and by spring sowing respectively, in the different seasons, cannot be at all adequately explained by the abstract given of rainfall and drainage alone. To do this, it would be necessary to go into detail as to the distribution of the rain, the coincident temperatures, and the condition of progress of the growing crop. But to bring prominently to view the effect of loss by drainage, it will be well to confine attention to the two extreme cases; the one in which the highest, and the other in which the lowest produce, of both corn and straw, was obtained after the autumn sowing of the ammonia-salts. These are 1874 and 1879.

In 1874, there was not only much more produce, both corn and straw, obtained by autumn than by spring sowing; but by autumn sowing there was then obtained the highest produce in the series, whether by autumn or by spring sowing. In 1879, on the other hand, autumn sowing gave not only much less than spring sowing, but much less than in any of the other cases of either autumn or spring sowing.

The following summaries bring prominently into contrast the produce of the two seasons, and the characters of the seasons themselves :—

Produce.

	Ammonia-salts, Autumn Sown.			Ammonia-salts, Spring Sown.			More (+) or less (−) by Spring Sowing.		
	Corn.	Straw.	Total.	Corn.	Straw.	Total.	Corn.	Straw.	Total.
	Bushels.	lbs.	lbs.	Bushels.	lbs.	lbs.	Bushels.	lbs.	lbs.
1874	$39\frac{3}{8}$	4645	7094	$29\frac{1}{8}$	2776	4588	$-10\frac{1}{4}$	−1869	−2506
1879	$5\frac{3}{8}$	906	1275	$16\frac{1}{4}$	3012	4063	$+10\frac{7}{8}$	+2106	+2788
1874 + or − 1879	+34	+3739	+5819	$+12\frac{7}{8}$	−236	+525			

Rainfall, and Drainage through 60-Inch “Drain-Gauge.”

	From Autumn Sowing to Spring Sowing.		From Spring Sowing to end of June.		Total From Autumn Sowing to end of June.	
	Rainfall.	Drainage.	Rainfall.	Drainage.	Rainfall.	Drainage.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1874	7·05	2·89	5·12	0·25	12·17	3·14
1879	15·05	13·09	12·86	4·95	27·91	18·04
1874 + or − 1879	− 8·00	−10·20	− 7·74	− 4·70	−15·74	−14·90

Thus, in 1874, the autumn-sown ammonia-salts gave $39\frac{3}{8}$ bushels of corn and 4645 lbs. of straw ; and $10\frac{1}{4}$ bushels more corn, and 1869 lbs. more straw, than the spring-sown ammonia. With this heavy crop by autumn-sown ammonia, and much heavier than by the spring sown, there were only 7·05 inches of rain from the date of autumn sowing to that of spring sowing, and only 2·89 inches of drainage through the 60-inch drain-gauge, during the same period. Then again, from the date of spring sowing to the end of June, there were only 5·12 inches of rain, and only 0·25 inch of drainage through the 60 inches of uncropped soil. It would appear that the small amount of winter rain was sufficient to aid the conversion of much of the ammonia of the manure into nitric acid, and for its distribution through the soil, favouring root-development; but that it was not sufficient for much loss by drainage. On the other hand, it would seem that the small amount of rain after the spring sowing, when both the progress of vegetation and the increasing temperature would serve to increase evaporation, was insufficient for the necessary conversion and distribution of the nitrogen of the spring-sown ammonia-salts.

Contrast this result, and these conditions, with those of 1879. In 1879 we have only $5\frac{3}{8}$ bushels of corn, and only 906 lbs. of straw, with the autumn-sown ammonia-salts; or 34 bushels less corn, and 3739 lbs. less straw, than by the same manures sown in the autumn for the crop of 1874. Coincidently with this result we have, for the season of 1879, 15·05 inches of rain, and 13·09 inches of drainage through 60 inches of soil, from the date of autumn sowing to that of spring sowing; or 8 inches more rain, and 10·2 inches more drainage, than over the same period for the crop of 1874. In 1879, however, we have $16\frac{1}{4}$ bushels of corn, and 3012 lbs. of straw, or $10\frac{7}{8}$ bushels more corn, and 2106 lbs. more straw, by spring sowing than by autumn sowing; and there were from the date of spring sowing to the end of June 12·86 inches of rain, and 4·95 inches of drainage through 60 inches; or 7·74 inches more rain, and 4·7 inches more drainage, than during the same perod in 1874. Further, whilst the drain-pipes in the experimental wheat-field did not run more than twice from the date of autumn sowing to that of spring sowing in the season of 1873–4, in the corresponding period of 1878–9 they ran about twenty times; and again, whilst from the date of spring sowing to the end of June they did not run at all in 1874, they ran six or seven times during the corresponding period in 1879. It is remarkable, that there was even more straw, though there was not more total produce, by spring sowing in the wet season of 1879, than in the dry one of 1874.

There can be no doubt that, in the season of 1878–9, there was an enormous loss by drainage from the autumn-sown ammonia-salts, not only during the winter, but also more or less afterwards; and that there was also a considerable loss from the spring-sown ammonia. In the season of 1873–4, on the other hand, whilst there seems to have been a sufficiency of rain during the winter for the action of the autumn-sown manure, it would appear that there was an actual deficiency for the proper action of the spring-sown ammonia-salts; resulting in even rather less straw, though still much more corn, than was obtained under the conditions of loss by drainage in 1879.

The quantity of ammonia-salts annually applied to each of these two plots is estimated to contain 82 lbs. of nitrogen; and the crops removed in the two years in question contained the following amounts of nitrogen :—

	Nitrogen in Produce per Acre.								
	Ammonia-salts, Autumn Sown.			Ammonia-salts, Spring Sown.			More (+) or less (−) by Spring Sowing.		
	Corn.	Straw.	Total.	Corn.	Straw.	Total.	Corn.	Straw.	Total.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1874	37·0	14·5	51·5	28·5	9·1	37·6	− 8·5	−5·4	−13·9
1879	6·6	5·7	12·3	17·6	13·8	31·4	+11·0	+8·1	+19·1
1874 + or − 1879	+30·4	+ 8·8	+39·2	+10·9	− 4·7	+ 6·2	..	..	..

The point of greatest interest is the contrast between the result obtained by autumn sowing in the dry season of 1874, and in the wet one of 1879. Whilst we have, in the produce of 1874, 51·5 lbs. of nitrogen, corresponding to 63 per cent. of the amount supplied, we have, in that of 1879, only 12·3 lbs., corresponding to only 15 per cent. of that supplied. In these calculations no allowance is made for the amount of nitrogen that the respective crops may have derived from the previously existing stores within the soil, irrespectively of the immediate supply by the ammonia-salts. It is obvious that, were any such allowance made, the result would appear even worse than is represented by the figures as they stand. It may be added, that such approximate estimates as we are able to make, founded on the amount of water passing through the 60-inch drain-gauge, and on the analyses of the drainage-waters collected from the autumn-sown plot, from the date of the autumn sowing up to harvest, would indicate an amount of loss of the supplied nitrogen by drainage sufficient to account, in great measure, for the defective yield.

With regard to the results relating to the spring sowing, it need only be noticed how much less of the nitrogen of the manure was recovered in the produce after spring sowing than after autumn sowing in the dry season of 1874 ; and how little more of the nitrogen of the spring-sown ammonia-salts was recovered in the crop in the too dry season of 1874, than in the very much too wet one of 1879, with all its loss by drainage.

The facts adduced can leave no doubt whatever that, independently of other adverse effects arising from low temperatures and excess of rain, the Rothamsted experimental wheat-crops of 1879 suffered very considerably from loss of the nitrogen of the manures by drainage. The question remains—whether land farmed and manured in the ordinary way would suffer in anything like the same degree from the same cause? The results of Professor Way, which have been referred to, clearly show that considerable loss may so arise when animal nitrogenous manures, such as hair, horn shavings, woollen rags, &c., are employed; and results obtained at Rothamsted show that there is a similar loss when vegetable nitrogenous manures, such as rape-cake, are used. Further, the drainage water from the dunged plot in the experimental wheat-field at Rothamsted is sometimes found to contain a considerable amount of nitric acid; but always very much less than that collected at the same time from adjoining plots receiving much less nitrogen as manure, but in the form of ammonia-salts or nitrate of soda. Whilst, therefore, it is to be assumed that the loss of the nitrogen of manure by drainage in the past season was proportionally much greater in the experimental wheat-field at Rothamsted than in the case of land farmed in the ordinary way, there can, nevertheless, be no doubt that much of the land of the country at large must also have suffered great loss in the same way.

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